IMPROVED RANGE RESISTORS FOR AC-DC TRANSFER MEASUREMENTS

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Abstract – This paper discusses the factors contributing to the ac-dc differences of high-voltage thermal converters. A novel resistor designed to minimize these contributions is described and measurements illustrating its performance are summarized.

INTRODUCTION

The development of a new generation of thermal transfer standards based on thin-film technology and MEMS-like structures has been undertaken. [1] The performance of the new thin-film, multijunction thermal converters (MJTCs) is close to that of existing national standards. Thermal transfer standards rated above a few tens of volts, high-voltage thermal converters (HVTCs), consist of a thermoelement (TE) in series with a multiplying resistor and are limited by the characteristics of multiplying range resistors. In general, the contribution of the resistor dominates the overall ac-dc difference of the HVTC [2]. The ac-dc difference of the HVTC may vary as functions of warm-up time, applied frequency, applied voltage, temperature, and possibly age. Voltage coefficients between 500 V and 1000 V can be several hundred μV/V or more for some worst-case resistors. A recent international intercomparison of HVTCs at high voltage and high frequency reported differences among the participating laboratories of as much as 122 μV/V in ac-dc difference at 1000 V and 50 kHz [3]. The resistors described in this paper were designed and constructed to minimize the effects of capacitance and temperature in order to reduce both the ac-dc difference and voltage coefficients of the HVTC.

CONSTRUCTION OF CONVENTIONAL HVTCs

In general, for HVTCs without internal shields, the ac-dc difference contribution from the transmission line effect, δ_T, can be expressed as [3]:

$$\delta_T \approx \frac{\omega^2}{6}\left[\frac{R_r^2 C_r^2}{30} - L_r C_r - L_{TE} C_{TE} - 2 L_{TE} C_r\right] \quad (1)$$

where ω is the angular frequency of the applied ac voltage, L_r, C_r, and R_r are the distributed inductance, distributed capacitance to the shield, and resistance of the multiplying range resistors, and L_{TE} and C_{TE} are similar parameters for the TE. Normally, the leading term will dominate this expression. If lower-order small quantities are neglected, then

$$\delta_T \approx \frac{\left(\omega R_r C_r\right)^2}{180} \quad (2)$$

Equation (2) indicates that ac current is bypassed through the distributed capacitance from the resistor to the shield, so less ac current flows through the thermoelement producing a positive ac-dc difference. The ac-dc differences calculated using this relationship are in general agreement with experimental results for such simple structures containing no internal shields. The calculated results indicate that the transmission line effect of input connectors, current standing-wave contribution in the TE, and skin effect in the cylinder or magnetic leads of the TE, all important for lower voltage ranges with a smaller volt-hertz product, can generally be neglected compared to the contribution to ac-dc difference shown in (2). The distributed capacitance between the unshielded range resistor and the outer cylinder, which permits ac current to bypass the TE to ground, is therefore a main source of error. In general, the distributed capacitances between all current carrying parts of the structure inside the external cylinder contain dielectric materials. The dielectric loss of the substrate for the resistors, if it is ceramic, may be very small and stable; however, the dielectric loss of any protective coating or insulating material may be much larger and may be temperature, and therefore voltage, dependent and may change with age.

IMPROVED HVTC RANGE RESISTORS

In conventional HVTCs, a driven internal shield structure is used to compensate, or reduce, the ac-dc difference at frequencies above 20 kHz. We describe new HVTC range resistors containing a novel internal shield structure that essentially eliminates the effect on the transfer function of stray capacitance from the main resistor body to the external grounded shield. The cancellation of the stray capacitance is made possible by the particular geometry of the internal shield elements and by the mounting location inside the resistor body. This construction eliminates the need for shunting a capacitive divider across the resistor and is the subject of a pending patent application [4]. A schematic diagram for the new resistor modules is shown in Figure 1.

The mechanical design consists of an outer perforated cylindrical body 10.5 cm long by 6.4 cm in diameter fitted with type GR-874 input and output connectors along with a 5 V dc power jack for the miniature internal cooling fan. An internal rectangular shield structure housing the main range resistor is supported inside the outer, safety ground cylinder by concentric butyl rubber rings. A photograph of the module is shown in Figure 2 and an exploded view is given in Figure 3.

PERFORMANCE OF NEW RANGE RESISTORS

The frequency response of the new range resistors has been trimmed to reduce the ac-dc differences at 50 kHz and 100 kHz, and the ac-dc differences has been measured against NIST working standards. The preliminary results are shown in Figure 4. The data show frequency flatness comparable to other well made HVTC range resistors with voltage coefficient between 500 V and 1 kV of less than 30 μV/V [5].

SUMMARY

We report the construction and availability of new high-voltage range resistors for thermal voltage converters based on novel shielding and frequency compensation. The new resistance modules have high resistance values making them suitable for small current applications such as new thin-film MJTCs and digital voltmeter circuits, yet the new compensation gives small voltage level dependence and good frequency flatness. The use of resistor elements with low temperature coefficients of resistance and an internal cooling fan gives quick warn-up and low thermal drift.

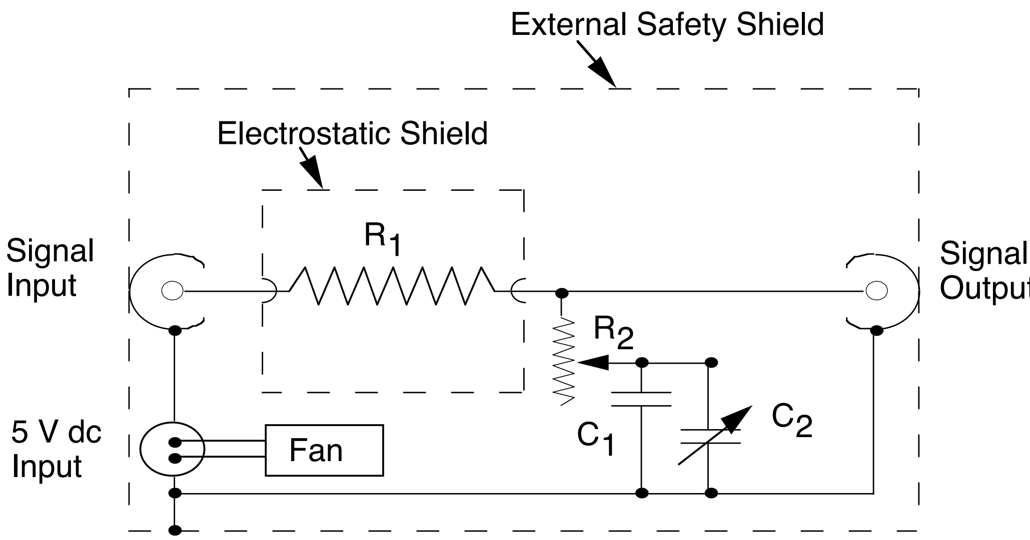

Figure 1. Schematic of the new resistor module.

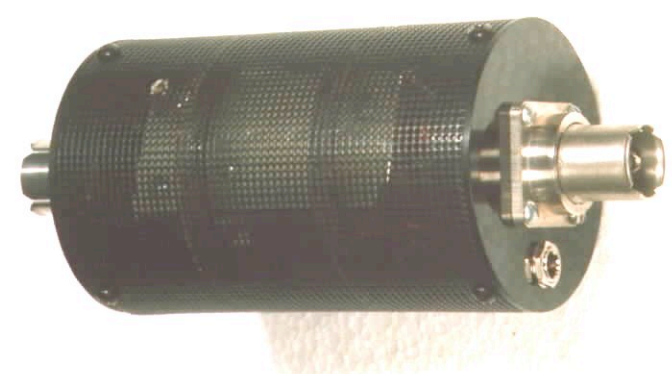

Figure 2. Exterior view of 1000 V range resistor.

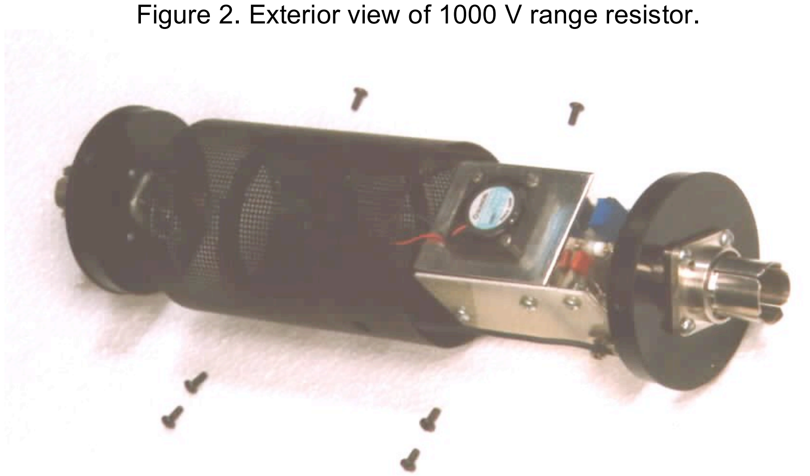

Figure 3. View of 1000 V range resistor showing internal structure.

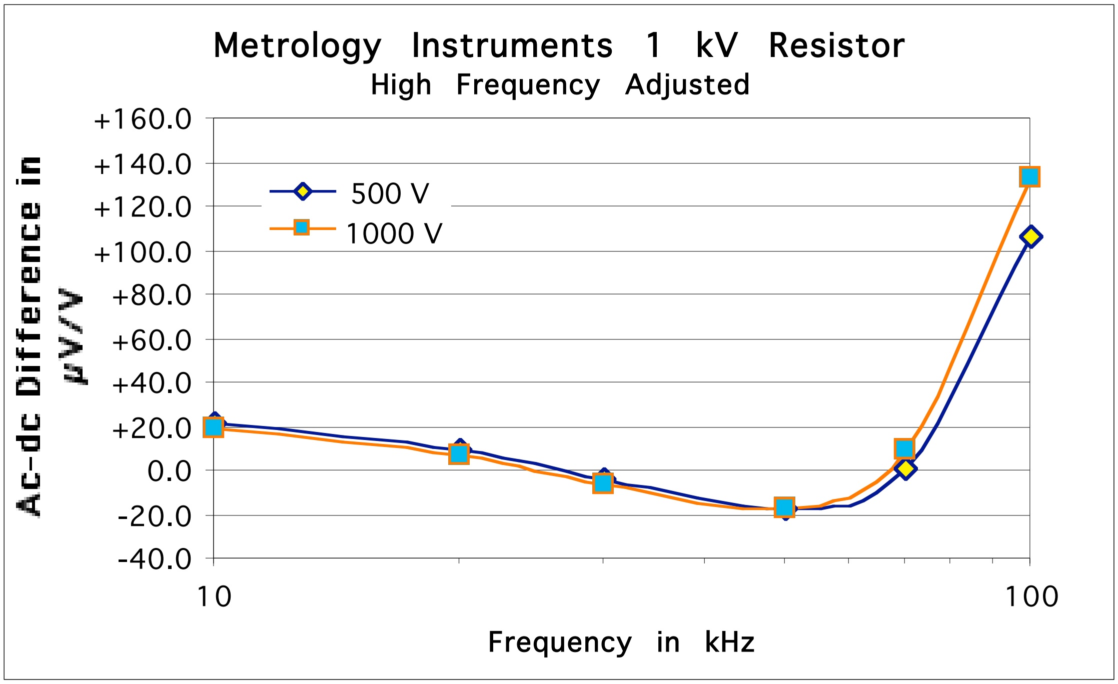

Figure 4. Preliminary results for a 1000-V resistor measured against NIST working standards. The frequency response of the resistor has been adjusted.

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